CONRAY®

(MEGLUMINE IOTHALAMATE
60% INJECTION)

RADIOLOGICAL TABLES
AND CIRCULAR SLIDE RULE

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INTRODUCTION AND RECOMMENDATION

INTRODUCTION

These radiological tables and circular slide rule were compiled and designed to provide a compact calculator and reference source to aid the radiologist or radiation therapist in his daily duties. The tables and diagrams provide a handy reference to many frequently used conversion factors, physical data, and clinically useful measurements. All tables, scales and graphs are engraved into a stable plastic that can be safely washed with mild soap and lukewarm water. The plastic case provides a carrier for the rule and pamphlet and will not easily slip out of a shirt pocket.

The easy-to-use circular slide rule has outer scales with a circumference of approximately eight inches, and as many subdivisions as a ten-inch slide rule. It is, therefore, sufficiently accurate for most calculations. As with all circular slide rules, the answer can never be off the scale. Problems involving multiplication, division, squares, square roots, proportion and inverse square can easily be solved. In addition, two newly devised scales — DT and T½ — are incorporated in the slide rule in order to simplify the calculation of tumor doubling time and radiation attenuation or radioactive decay.

All diagnostic radiological data are confined to the external reverse side whereas both surfaces of the insert contain data of importance to the radiation therapist. Rulers with accurate centimeter and inch scales are provided on the reverse. A protractor is provided on the insert. A temperature conversion chart is enscribed near the center of the circular sliding scale. A star is enscribed on the front surface of the slide rule face and the insert as an index to permit rapid recollection of scale positions.

RECOMMENDATION

It is recommended that this slide rule neither replace an excellent physics text or physics course, nor should it replace hard-won clinical knowledge. However, the device does provide a tabulation of useful data, a refresher course in physics, and a simple means for calculations for those who have studied and mastered the basic problems.

GRAPHS AND TABLES

FOR THE DIAGNOSTIC RADIOLOGIST

The entire back surface of the slide rule presents the following diagnostic radiological charts:

1. Pineal localization (Vastine-Kinney Method)

A lateral drawing of the skull identifies the measurements to be used. The letters indicate the greatest distance in centimeters from the pineal body to

inner table of frontal bone .... **A**
inner table of occiput .... **B**
inner table of vault .... **C**
inner table of occiput (foramen magnum) in vertical direction ..... **D**

The upper graph is for superior-inferior localization. Plot **C** on the vertical axis and **C+D** on the horizontal axis. The point of intersection should normally lie within the stippled (gray) band. If abnormal, the graph shows the amount and direction of displacement. The lower graph is used for anterior-posterior localization. In this graph, **A+B** is plotted on the vertical and **A** on the horizontal axis. The point of intersection again normally should lie within the gray zone. If abnormal, the direction and amount of displacement are shown.[1]

2. Skull size

External measurements of the skull in centimeters are obtained from anterior-

posterior and lateral radiographs exposed at 40 inches focal-film distance. On the skull diagrams supplied, lines are drawn to simulate actual measurements. They are defined as

Length **(L)** — distance from glabella to opisthocranion
Height **(H)** — distance from apex of vault to basion
Width **(W)** — greatest biparietal distance

The measurement for each distance is compared directly with the stated normal in the table for the same sex and age as those of the particular patient under study.[2] Deviations from the normal merit investigation by appropriate clinical or roentgenological study.

3. Bone age (epiphyseal centers)

Radiographs of all joints of the extremities of one side of the body, including hip and shoulder, are obtained and all calcified epiphyseal centers corresponding to those engraved in black in the diagram are counted. The number counted is compared with the normal value listed for the chronological age and sex of the child being evaluated. Sigma (σ) represents the standard deviation. More than two standard deviations represent probable abnormality.[3]

4. Interpediculate distance of dorsolumbar spine

The interpediculate width of each vertebra is measured in millimeters and

plotted on the graph. The curve so formed is compared with the appropriate maximum normal curve for the patient's chronological age. Two variations are abnormal:

a. Enlargement above normal maximum values;
b. Abrupt localized enlargement even if in an otherwise normal curve.[4]

FOR THE RADIATION THERAPIST

1. Characteristics of radioactive isotopes

The following characteristics of 38 radioactive isotopes of 26 elements are tabulated on the back surface of the insert: name, symbol with atomic number subscript and mass number superscript, half-life, decay product and the principal energies of the radiations emitted including electrons (B—), positrons (B+) and gamma rays. For convenience, the 0.511 MeV x-rays resulting from the annihilation reaction associated with positron emission are included in the gamma column. The K gamma factor (dose in roentgens per hour at 1 cm. from a 1 mci. point source) and half value layer in lead are listed for commonly used gamma emitters.

In the case of multiple or conflicting values, those most often employed clinically were selected.[5]

2. Constants, formulas, conversion units

The remainder of this side (back) of the insert presents constants, formulas, and definitions required for radioactive decay and radioactivity determinations. Formulas for calculating radioactive decay, effective life, average life, isotope decay equilibrium and mgm radium equivalent are included.[6]

3. Statistical significance graph

The minimum number of cases divided into two equal groups that would be required to reach a significant result at the 5% level (P = 0.05) can be determined from the graph on the front surface of the insert.

The graph is used by locating the lower percentage result on the horizontal axis and the difference in the percentages of results on the curves vertically above. The number on the vertical axis opposite this intersection indicates the total number of cases required for significance.

By inspection it is apparent that the greater the difference between the two groups, the smaller the total number of cases necessary to show a significant result. Fewer cases are required at the ends of each curve than in the central portion to show the same difference between C_2 and C_1 at a significant level. It must be kept clearly in mind that rigorous conditions (an appropriate rep-

resentative sample randomly allocated to the two groups) must be demonstrated as in any other statistical procedure.[7]

4. Brachytherapy sources

The approximate half value layer in lead and tissue of isotope sources commonly used in brachytherapy (interstitial or intracavitary) are listed.[8]

5. Teletherapy sources

The characteristics of commonly used teletherapy units are expressed in tables presenting the relationship between the energy or isotope of the unit and the depth in millimeters in the tissue at which electronic equilibrium is obtained (maximum dose).[6]

Data are presented regarding the attenuation of radiations from external therapy units. In the case of attenuation by lead, the conventional half-value layer value is expressed. It is notable that while a very small thickness of lead is sufficient to shield or block out 250 KV x-rays, and a much larger amount for the isotope units, surprisingly, the 24 MeV Betatron has a HVL in lead only slightly greater than the cobalt 60 units. In the listing of attenuation of radiation by tissue, the value expressed is not truly the HVL, but rather the thickness of tissue required to reduce the dose to 50% of the maximum dose. In this circumstance, the value presented represents the depth of the 50% dose (D½) obtained

from central axis depth dose tables as recorded for a field 10x10 cm and a focal distance of 100 cm. Therefore the data represents values obtained from the clinical situation. The physical parameters concerned in expression of this depth are: (1) FSD, (2) HVL of radiation, (3) field size, and (4) depth of electronic equilibrium. For clinical purposes, it is necessary to know this value of depth of 50% dose to permit comparison of penetrating radiations and also for calculation of integral dose. For ease of comparison of penetrability, all of the values have been normalized to 100 cm FSD. Obviously if a shorter FSD or SSD or a smaller field be used, the depth of 50% dose would be less.[6]

CIRCULAR SLIDE RULE

BASIC USAGE

1. Theory

The slide rule uses a simple mechanism to permit rapid and accurate solution of problems of multiplication, division, proportion, squares and square roots. The basis of this mechanism is the slide rule scale which represents the logarithm of a number by a length on the scale. From algebra we recall that a logarithm of a number is an exponent to some base. We further recall the following relations:

$$A^x \times A^y = A^{x+y}$$
$$A^x \div A^y = A^{x-y}$$
$$(A^x)^y = A^{xy}$$

Thus to multiply we add exponents, to divide we subtract exponents and to raise to a power we multiply exponents. Since the slide rule represents exponential scales, it is possible to perform the functions by adding or subtracting distances. The answers are read directly from the slide rule scale.

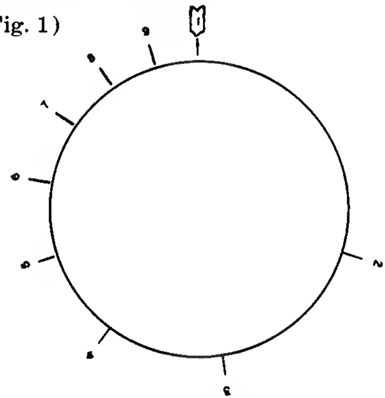
It is important to remember that a slide rule, by its very nature, does not provide exact answers. The last significant figure of a number read on any slide rule is always uncertain.

The greatest difficulty in the use of the slide rule arises from difficulties in reading the scales. Some practice is required to learn to read the scales, but the effort demanded is repaid many fold in time saved in later calculations.

2. Reading the scales

In locating a number on the C scale, for example, the decimal point is ignored and the number can be read to at least three significant digits. The scale is divided into nine primary divisions labelled as follows:

(Fig. 1)



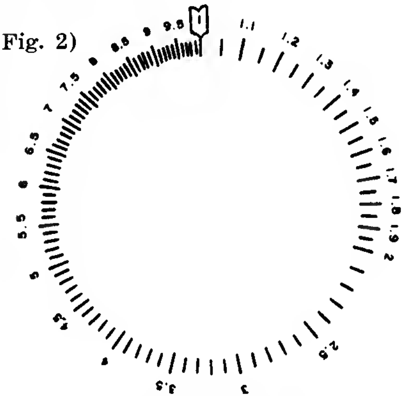
1st significant digit

The variation in spacing between the divisions is due to the logarithmic nature of the scale.

The 1 on the C or D scale is called the index (⍓). One of these primary divisions will always represent the first significant digit of a number. Any number whose first significant digit is 2 will be located between primary divisions 2 and 3. The following shows how to find exactly

where. Each of the above primary divisions is in turn divided into secondary divisions. Between primary 1 and 2, space permits each of the secondary divisions to be labelled (Fig. 2).

(Fig. 2)

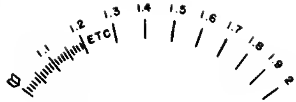


2nd significant digit

Between the other primary divisions, however, only the fifth secondary division is labelled, but this suffices to orient the user. The secondary divisions represent the second significant digit in a number unless the second significant number is zero, in which case it would be represented by a primary division.

Tertiary divisions fall into three different categories depending on the space available for these divisions. Between 1 and 2 where most space is available, there are ten divisions, each having a value of one (Fig. 3).

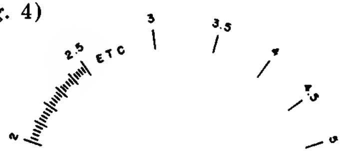
(Fig. 3)



3rd significant digit 1-2

Between primary divisions 2 and 5, the tertiary divisions are limited to five between each secondary division; consequently, each of these tertiary divisions has a value of 2. It is easy to interpolate between them for odd third significant digits (Fig. 4).

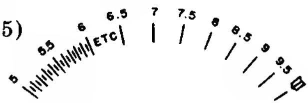
(Fig. 4)



3rd significant digit 2-5

From 5 through 10, space becomes more limited and there is only one tertiary division between each secondary division. Its value is five. In this range interpolation is much more important and can be done very proficiently with practice (Fig. 5).

(Fig. 5)



3rd significant digit 5-10

3. Multiplication

Two identical scales, C and D, are used for multiplication. The decimal point is ignored in locating a number on these scales.

Problem: Multiplying 245×1.34.

Locate 245 on the D scale, and line up ⌂ on the C scale with it. Set the hairline to 1.34 on the C scale. The hairline shows the answer, 328, on the D scale. Supply the decimal point by estimating the general magnitude of the number.

(Fig. 6)

Multiplication

4. Division

Division is the inverse of multiplication and is done in precisely the inverse fashion, using again the C and D scales.

Problem: 328÷1.34.

Locate 328 on the D scale with the hairline and line up 1.34 on the C scale with it. The index ⌂ on the C scale marks the answer, 245, on the D scale. Again, the decimal point is determined by approximation.

(Fig. 7)

Division

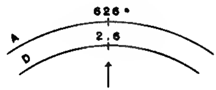
5. Squares and square roots

Since the A scale represents the square of the D scale any number on the A scale is the square of the corresponding D scale number, and similarly any number on the D scale represents the square root of the A scale value. Similarly the B scale represents the square of the C scale.

Problem: What is the square of 2.5?

1. Place hairline at 2.5 on D scale.
2. Read 625 on A scale.
3. Place decimal point 6.25.

(Fig. 8)

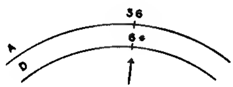


Square of a number

Problem: What is the square root of 36?

1. Place hairline at 36 on A scale.
2. Read 6 on the D scale.

(Fig. 9)



Square root

Note that the A scale and B scale each have two cycles, 1 to 10 and 10 to 100. To find square roots of numbers less than 1 or greater than 100, it is convenient to

transform the number to a value between 1 and 100, times 10 to an even power. For example:

$$\sqrt{90000} = \sqrt{9 \times 10^4} = \sqrt{9} \times \sqrt{10^4} = \sqrt{9} \times 10^2$$

$$\sqrt{0.009} = \sqrt{90 \times 10^{-4}} = \sqrt{90} \times \sqrt{10^{-4}} = \sqrt{90} \times 10^{-2}$$

The $\sqrt{9}$ and $\sqrt{90}$ are then found, using the A and D scales as above, to be 3 and 9.49. Thus:

$$\sqrt{90000} = 3 \times 10^2 = 300$$

$$\sqrt{0.009} = 9.49 \times 10^{-2} = 0.0949$$

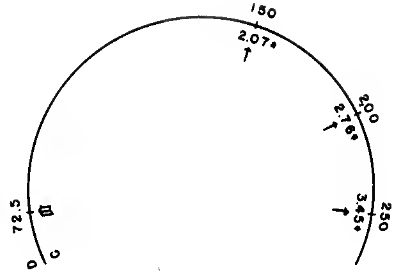
6. Proportion

A very convenient feature of the C and D scales is that at any relative setting of the two scales, the same ratio exists between all numbers on the C scale and the numbers opposite them in the D scale.

Problem: An x-ray therapy machine has an output at 50 cm of 72.5 roentgens per minute. Find the treatment times to deliver doses of 150, 200 and 250 roentgens.

1. Place the index of the C scale under 72.5 on the D scale. Now all numbers on the D scale represent roentgens and the numbers opposite on the C scale represent minutes.
2. Move the hairline respectively on the D scale to 150, 200 and 250 and read the corresponding treatment times on the C scale as 2.07, 2.76 and 3.45 minutes.

(Fig. 10)



Proportion

SPECIAL RADIOLOGICAL APPLICATIONS

1. Inverse square problems

Problems involving inverse squares are frequent and can be solved readily using the C and D scales in conjunction with the A and B scales.

Example:

Find the dose rate at 76 cm from a Co_{60} teletherapy machine known to have an output of 82 R/min. at 55 cm. The solution of this problem depends on the relation previously described.

$$\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2}$$

Where I = intensity
d = distance

In this expression we substitute these values

$$\frac{82}{x} = \frac{(76)^2}{(55)^2}$$

This problem would usually require some time and effort to rearrange the terms before any arithmetical calculation was undertaken. With the slide rule, however, the equation offers a direct analogy to its set up, as each term occupies the same position in the slide rule setting as in the equation. Thus, it is possible to learn one setting of the slide rule to solve for any one of the terms of the equation. Simply set the slide to the known values on the scale corresponding to the equation and read the answer on the proper scale, again corresponding to the equation.

$$\boxed{\frac{I_1\ (\text{A scale})}{I_2\ (\text{B scale})} = \frac{d_2\ (\text{D scale})}{d_1\ (\text{C scale})}}$$

Until familiar with this technique, it is probably of value to write this simple equation for each problem to aid in the slide rule set up and reading the answer.

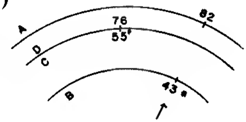
Step 1. Place the hairline on the new distance $D_2 = 76$ on the D scale.

Step 2. Place the distance of the known output $D_1 = 55$ on the C scale under the hairline.

Scales A and B whose numbers are the squares of the corresponding numbers on the scales C and D are now set so that they are in the ratio of the squares of 76 and 55. Since we are interested in the inverse squares, the B scale represents dose rates at 76 cm SSD while the A scale represents corresponding dose rates at 55 cm SSD.

Step 3. Move the hairline to 82 on the A scale to read the answer, 43 R/min. on the B scale beneath the hairline.

(Fig. 11)



Inverse Square

2. T½ scale and use

The T½ scale is used to permit rapid and accurate solution of problems concerned with radioactive decay or radiation attenuation.

The T½ scale is the outer of the two scales with the orange numeral markings. Note that the index of the T½ scale is labelled 0 (zero).

In order to prevent error and confusion, the T½ scale will be indicated in orange to differentiate this concept from the concept T½ (Half Life or Half Value Layer). The relation between the two concepts will be fully explained.

The T½ scale is a label of the number of half lives or half value layers with a range from 0 to 3.32 with divisions to the nearest 1/100th. The distance on the scale actually represents a Dose Reduction Factor which can be read when

required from the C scale opposite the value on the T½ scale. This Dose Reduction Factor in isotope or radiation attenuation problems is the ratio between the original value of intensity of the source or beam and the modified value of intensity of the source or beam. This factor is obviously related to the number of half lives or half value layers occurring. The relationship between the Dose Reduction Factor and the number of half lives or half value layers is represented by the relation between the C scale and the T½ scale.

The number on the T½ scale indicates the power to which the number 2 must be raised to give the corresponding value on the C scale, i. e., 3 on the T½ scale means three half lives or 2^3 or 8, which is the value immediately above on the C scale and which represents the Dose Reduction Factor associated with 3 half lives.

This method of labelling makes it possible to use the T½ scale directly with the D scale to solve with remarkable ease the common decay and attenuation problems. A number on the T½ scale bears the following relationship to the particular half life of an isotope or half value layer for the radiation and barrier being considered.

$$\#T\tfrac{1}{2} = (\text{number on } T\tfrac{1}{2} \text{ scale})$$

$$\#T\tfrac{1}{2} = \frac{\text{Time of decay}}{\text{Half life of isotope}} = \text{Number of half lives}$$

$$\#T\tfrac{1}{2} = \frac{\text{Thickness of barrier}}{\text{Half value layer for this material and radiation}} = \text{Number of half value layers}$$

Decay times and barrier thicknesses must be expressed in the above manner (number of HVL or half lives) for use on the T½ scale.

By substituting for the familiar and general expression

$$I_t = I_o e^{-\gamma t}$$

the equivalent expression*

$$I_t = \frac{I_o}{2^{t/T\frac{1}{2}}}$$

problems can be easily solved. The expression $2^{t/T\frac{1}{2}}$ = dose reduction factor appears as the number on the C scale when $(t/T\tfrac{1}{2})$ which represents the number of HVL is placed on the T½ scale.

*Footnote:

$$I_t = I_o e^{-\gamma t} = I_o e^{-.693t/T\frac{1}{2}}$$

$$I_t = \frac{I_o}{e^{+0.693t/T\frac{1}{2}}}\,;\ \ln 2 = 0.693 \quad \therefore \quad e^{+.693} = 2$$

$$\therefore \quad \left(e^{.693}\right)^{t/T\frac{1}{2}} = 2^{t/T\frac{1}{2}} \quad \therefore \quad I_t = \frac{I_o}{2^{t/T\frac{1}{2}}}$$

In this form, the equation also offers a direct analogy to its set-up on the slide rule because each term occupies the same relative position on the slide rule as in the equation. The analogy makes it possible to learn one simple way of setting up the problem on the slide rule to solve the equation when any one of the three terms is unknown. The set-up is as follows:

1. I_t, the remaining intensity or activity, is read on the D scale opposite the index of the T½ scale (which coincides with the index of the C scale).
2. I_o, the initial intensity or activity, is on the D scale beneath the hairline.
3. T½, the number of half lives or HVL, is on the T½ scale beneath the hairline.

$$\frac{I_t \text{ (D scale)}}{1 \text{ (C scale)}} = \frac{I_o \text{ (D scale)}}{T\frac{1}{2} \text{ (T}\frac{1}{2}\text{ scale)}}$$

It is seen that any two of these values suffice to establish the slide rule setting. The third value, the unknown, can then be read from its corresponding position in the slide rule set-up.

Note that the T½ scale extends only to 3.32 ($2^{3.32} = 10$). In order to solve problems involving more than 3.32 half lives or half value layers, the exponents can be considered as addenda, or in the case where large values of Dose Reduction Factor or T½ are involved, it is reasonable to consider multiples of 3.32 for each factor of 10 in Dose Reduction Factor.

While the slide rule allows rapid and accurate solution of problems of attenuation and decay when precise answers are required, such precision is often not necessary. In cases where an approximate value is all that is required, it is possible to use the approximation $2^{10} \cong 10^3$, i. e., a dose reduction by a factor of 10 half value layers is nearly equivalent to a reduction by 1000. The approximations

$$2^{10} \cong 10^3$$
$$2^{20} \cong 10^6$$
$$2^{30} \cong 10^9$$

arise from the solution of the exponential

$$2^{10} = 1024$$
$$\therefore 2^{10} \cong 10^3 \text{ (1000)}$$

Similarly, $2^{20} = 2^{10\times2} = 2^{10} \times 2^{10}$

$$= 10^3 \times 10^3$$
$$= 1000 \times 1000 = 10^6$$

Thus, a reduction by 20 half value layers is equivalent to a dose reduction by a factor of one million. In the case of protection problems or decay problems involving many half value layers or half lives, such an "order of magnitude" solution is frequently all that is required.

3. Radioactive decay problems

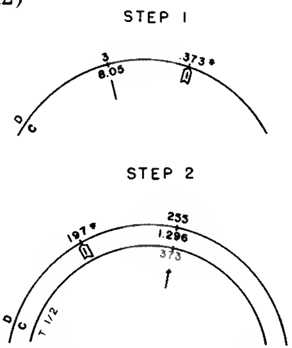
Various problems of clinical interest regarding radioactive decay follow. The

solution of each type of problem will be shown by an example.

Problem 1: Calculate residual activity. A shipment containing 255 mci of I_{131} is to be used 3.0 days after the above measurement was made. If I_{131} has a half life of 8.05 days, find the activity remaining.

1. The number of half lives transpired is $3 \div 8.05 = 0.373$ half lives (using the C and D scales as described under division).
2. Place the hairline over the original activity, 255, on the D scale.
3. Move the half lives transpired, .373, on the T½ scale beneath the hairline.
4. Read the answer on the D scale at the index of the C scale — 197 mci.

(Fig. 12)



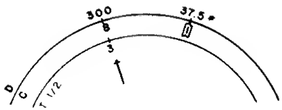
Radioactive decay — Example 1

Problem 2: Calculate residual activity. If 300 mci of Au_{198}, whose half life is 2.7 days, have decayed for 16 days, find the remaining activity.

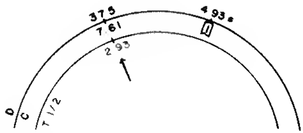
1. The number of half lives transpired is $16 \div 2.7 = 5.93$.
2. This value is greater than the range of the T½ scale. Arbitrarily divide 5.93 into two portions, i. e., $5.93 = 3.00 + 2.93$.
3. Place the hairline over the original activity (300 mci) on the D scale.
4. Rotate the disc so that the first increment of transpired half lives — 3 half lives — on the T½ scale is directly under the hairline. This is equivalent to dividing by the dose reduction factor, which is 8.
5. Place the hairline at the intermediate answer on the D scale at the index of the C scale; answer — 37.5 mci.
6. Leaving the hairline at 37.5 on the D scale, rotate the disc till the remaining increment of half lives — 2.93 — on the T½ scale is directly under the hairline. This is equivalent to dividing by the dose reduction factor, 7.61.
7. Read the remaining activity on the D scale at the index of the C scale. Answer: 4.93 mci.

(Fig. 13)

STEP 1



STEP 2



Radioactive decay — Example 2

In this example, it will be noted that the remaining activity after decay of 3.00 half lives then becomes the initial activity for the following 2.93 half lives. In this manner, the problem is solved simply and rapidly.

Similar use of the equation and analogous slide rule settings provide the rapid and easy means of solution for any of the terms which might be unknown.

4. Radiation attenuation problems

Radiation attenuation problems are exactly analogous to the radioactive decay problems and are solved in precisely the same steps by the same slide rule set-up. However, since the problems often represent protection problems where the

Dose Reduction Factor is quite large — from 100 to 1000 or more, it is often useful to consider that each Dose Reduction Factor of 10 requires 3.32 half value layers. The use of this concept in shielding problems is demonstrated.

Problem 1. Find the thickness of a concrete wall required to reduce the intensity of radiation from a Co_{60} teletherapy unit at the surface of the wall from 6500 R per week to a permissible level of 0.1 R per week if the HVL of Co_{60} in concrete is 2.5 inches.

1. The required reduction factor is $6500 \div 0.1 = 65000 = 6.5 \times 10^4$.

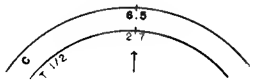
2. Place the hairline over 6.5 on the C scale and read the corresponding number of HVL, 2.7 on the T½ scale.

3. The 10^4 portion of the desired dose reduction factor requires 3.32 HVL for each reduction by a power of 10. Thus for a reduction by a factor of 10^4 requires 4×3.32 HVL. The total number of HVL required is thus:
   $2.7 + (4 \times 3.32) = 15.98$ or 16

4. The thickness of concrete required is 2.5 inches/HVL $\times$ 16 HVL $=$ 40 inches.

(Fig. 14)

STEP 1



STEP 2

Radiation Attenuation
Example I

5. DT scale and use

The DT scale is used in conjunction with the A scale for determination of the apparent doubling time of a tumor whose diameter is measured on two radiographs taken at a known interval of time. The DT scale is the inner scale with the orange numerical markings.

The concept of doubling time assumes that the growth rate of a tumor is constant. Over the entire life of the tumor, this has been refuted by both clinical and experimental evidence, but the doubling time calculation can be used to aid in diagnosis as to whether a given lesion is benign or malignant. In addition, the effects of treatment may be reflected in a change in growth rate.[9]

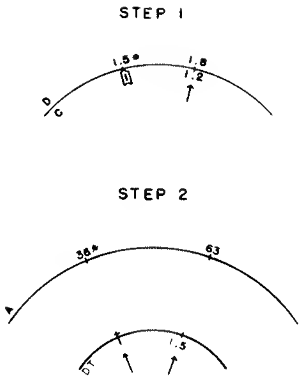
6. Tumor doubling time problem

The diameter of a nodule seen on two separate chest films taken 63 days apart increased from 1.2 cm to 1.8 cm. Find the apparent doubling time of the tumor. The accompanying formula permits simple slide rule set up by analogy to the equation:

$$\frac{\text{Apparent DT (A scale)}}{\underset{\text{(arrow)}}{\uparrow} \qquad \text{(DT scale)}} = \frac{\text{Time interval (A scale)}}{\text{Ratio of diameters (DT scale)}}$$

1. Find the ratio of the larger diameter to the smaller using the C and D scales.
   $1.8 \div 1.2 = 1.5$
2. Locate the time interval, 63, on the A scale with the hairline.
3. Bring the ratio of diameters, 1.5, on the DT scale beneath the hairline.
4. Move the hairline to the arrow on the DT scale.
5. The apparent doubling time, 36 days, is read under the hairline on the A scale.

(Fig. 15)



Doubling time — Example 1

ACKNOWLEDGMENTS

Interpediculate space
From Simril, Wayne A. and Thurston, Donald L. *Radiology*, Vol. 64, page 340, March 1955.

Pineal localization
From Taveras, J. M. and Wood, Ernest H. *Diagnostic Neuroradiology*. Baltimore, Maryland, The Williams & Wilkins Company, 1964. Pages 1.27 & 1.31.

Bone age
Elgenmark, O. *Acta Paediat.*, Vol. 33, Supp. 1, 1946.

Statistical graph
Boag, John W. *Journal of Faculty of Radiologists*, Vol. 11, No. 3, page 151, 1960.

Skull size
Haas, Lewis L. *Am. J. Roentgen.*, Vol. 67, p. 197, 1952.

BIBLIOGRAPHY

1. Taveras, J. M. and Wood, Ernest H. *Diagnostic Neuroradiology*. Baltimore, Maryland, The Williams and Wilkins Company, 1964. Pages 1.27 and 1.31.

2. Haas, Lewis L. Roentgenological Skull Measurements and Their Diagnostic Applications. *American Journal of Roentgenology, Radium Therapy and Nuclear Medicine*, Vol. 67, #2, pp 197-209, February, 1952.

3. Elgenmark, Olle. The Normal Development of the Ossific Centers During Infancy and Childhood. *Acta Paediatrica*, Vol. 33, Supplementum #1, 1946.

4. Simril, Wayne A. and Thurston, Donald L. The Normal Interpediculate Space in the Spines of Infants and Children. *Radiology*, Vol. 64, p 340, March 1955.

5. *Radiological Health Handbook*, Revised Edition, September 1960. U.S. Dept. of Health, Education and Welfare, Public Health Service.

6. Johns, Harold E. *The Physics of Radiology*. Springfield, Illinois, Charles C Thomas, 1961.

7. Boag, John W. Statistical Problems Which Arise in Cancer Therapy. *Journal of Faculty of Radiologists*, Vol. 11, #3, pp 150-155, July 1960.

8. Thoraeus, R. Attenuation of Gamma Radiation from ^{60}Co, ^{137}Cs, ^{192}Ir, and ^{226}Ra in Various Materials Used in Radiotherapy. *Acta Radiologica*, Vol. 3, Fasc. 2, pp 81-86, April 1965.

9. Spratt, John S., Ter-Pogossian, M. and Long, Robert T. L. The Detection and Growth of Intrathoracic Neoplasms. *Archives of Surgery*, Vol. 86, pp 283-288, February 1963.

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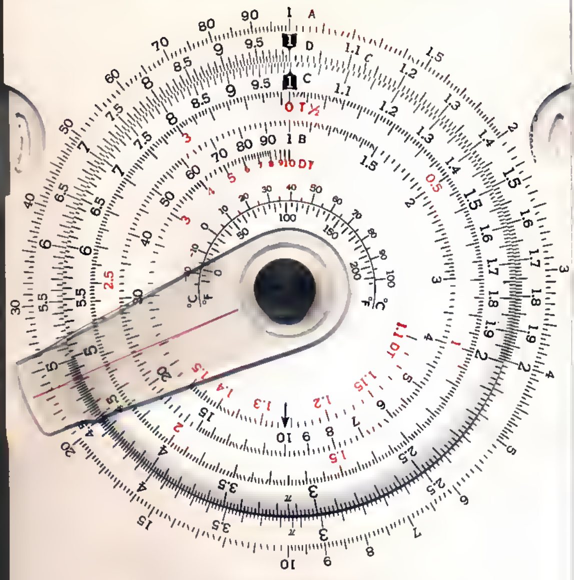

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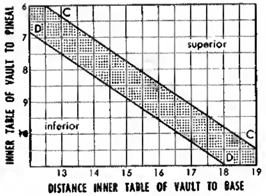
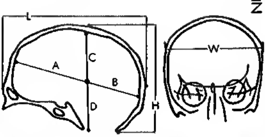
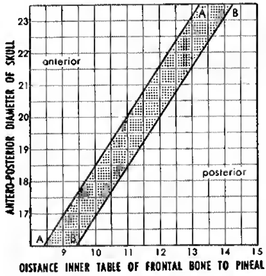
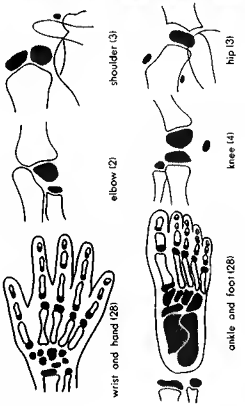




NORMAL SKULL SIZE DEVELOPMENT
40 inch focal distance

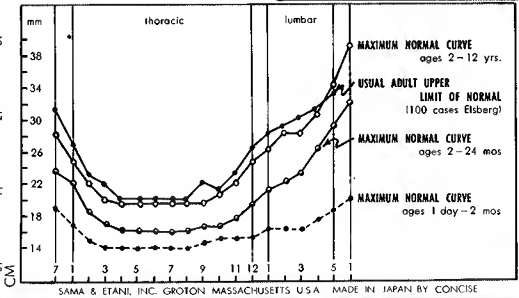
age	length (cm)	height (cm)	width (cm)
Males			
4 wk	13.9	10.7	11.3
2– 6mo	14.7	11.7	12.2
7–12mo	16.4	13.3	13.9
13–18mo	17.1	14.0	14.1
19–30mo	18.1	14.7	15.1
3– 5yr	18.9	14.9	15.3
6– 8yr	19.4	15.2	15.9
9–11yr	19.6	15.3	16.0
12–14yr	20.3	15.6	16.2
15–17yr	20.6	15.7	16.5
18–20yr	20.8	15.6	16.5
21 yr	21.2	15.6	16.8
Females			
4 wk	13.2	11.1	10.8
2– 6mo	14.3	11.8	11.6
7–12mo	15.8	12.4	13.2
13–18mo	17.1	13.6	13.9
19–30mo	17.7	14.2	14.4
3– 5yr	18.8	14.6	14.9
6– 8yr	19.0	14.8	15.3
9–11yr	19.3	14.8	15.5
12–14yr	19.7	15.1	15.7
15–17yr	20.1	15.0	15.7
18–20yr	20.1	15.1	16.1
21 yr	20.1	15.1	16.2





NUMBER OF EPIPHYSEAL CENTERS BY AGE IN MONTHS

age months	boys M	boys σ	girls M	girls σ
1	4.8	1.9	4.7	1.9
2	5.7	2.0	6.2	2.3
3	6.5	2.0	7.6	2.5
4	8.9	2.8	8.5	2.8
5	9.8	2.4	10.4	2.0
6	11.2	2.4	11.5	1.7
7	12.5	2.9	12.9	1.4
8	13.0	1.7	14.6	3.5
9	13.6	2.7	16.3	2.4
10	15.2	3.5	18.1	4.4
11	15.8	3.2	22.7	6.9
12	16.5	4.9	25.1	8.7
13–15	19.9	6.3	28.6	9.2
16–18	23.5	8.4	32.9	8.8
19–21	25.5	8.4	41.3	8.6
22–24	32.3	9.2	47.2	7.1
25–27	36.8	5.5	50.8	4.8
28–30	39.8	8.4	53.2	6.5
31–33	44.1	4.8	55.8	4.8
34–36	48.5	5.8	60.5	3.0
37–42	49.5	6.9	59.5	4.5
43–48	56.6	4.9	61.4	6.6
49–54	59.3	5.5	63.5	2.2
55–60	61.8	3.5	64.2	2.3



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ISOTOPES

element		half life	decay product	principle energy (MeV) β−	β+	gamma	K gamma	HVL Pb(cm)
Hydrogen	$_1H^3$	12.26 Y	$_2He^3$	0.018				
Carbon	$_6C^{11}$	20.4 M	$_5B^{11}$		0.98	0.511	6.2	
	$_6C^{14}$	5600 Y	$_7N^{14}$	0.156				
Nitrogen	$_7N^{13}$	9.98 M	$_6C^{13}$		1.19	0.511		
Oxygen	$_8O^{15}$	2.05 M	$_7N^{15}$		1.68	0.511		
Fluorine	$_9F^{18}$	1.87 H	$_8O^{18}$		0.65	0.511		
Sodium	$_{11}Na^{22}$	2.58 Y	$_{10}Ne^{22}$		0.54	0.511	13.2	1.0
	$_{11}Na^{24}$	15 H	$_{12}Mg^{24}$	1.39		1.37	19.0	1.5
Phosphorus	$_{15}P^{32}$	14.2 D	$_{16}S^{32}$	1.71				
Sulfur	$_{16}S^{35}$	87.1 D	$_{17}Cl^{35}$	0.167				
Potassium	$_{19}K^{42}$	12.5 H	$_{20}Ca^{42}$	3.55		1.53	1.4	
Calcium	$_{20}Ca^{45}$	164 D	$_{21}Sc^{45}$	0.254				
	$_{20}Ca^{47}$	4.7 D	$_{22}Ti^{47}$	0.44		1.31		
			$_{21}Sc^{47}$	0.61		0.159		
				2.0				
Chromium	$_{24}Cr^{51}$	27.8 D	$_{23}V^{51}$			0.32	0.17	0.2
Iron	$_{26}Fe^{59}$	45.1 D	$_{27}Co^{59}$	0.27		1.10	6.8	1.1
				0.46		1.29		
Cobalt	$_{27}Co^{57}$	270 D	$_{26}Fe^{57}$			0.014		
						0.123		
	$_{27}Co^{58}$	72 D	$_{26}Fe^{58}$		0.48	0.814	5.7	
	$_{27}Co^{60}$	5.26 Y	$_{28}Ni^{60}$	0.31		1.17	13.4	1.2
						1.33		
	$_{27}Co^{61}$	1.65 H	$_{28}Ni^{61}$	1.22		0.07		
Copper	$_{29}Cu^{64}$	12.8 H	$_{30}Zn^{64}$	0.57		1.34		
			$_{28}Ni^{64}$		0.657	0.511	1.2	0.4
Gallium	$_{31}Ga^{68}$	68 M	$_{30}Zn^{68}$		1.9	0.511		

element		half life	decay product	principle energy (MeV) β−	β+	gamma	K gamma	HVL Pb(cm)
Arsenic	$_{33}As^{74}$	17.5 D	$_{32}Ge^{74}$	1.36	0.91	0.59		
			$_{34}Se^{74}$		1.53	0.511		
Selenium	$_{34}Se^{75}$	121 D	$_{33}As^{75}$			0.136	1.84	
						0.265		
						0.280		
Strontium	$_{38}Sr^{85}$	65 D	$_{37}Rb^{85}$			0.513	3.2	
	$_{38}Sr^{90}$	28 Y	$_{39}Y^{90}$	0.543				
			$_{40}Zr^{90}$	2.24				
Technetium	$_{43}Tc^{99m}$	6 H	$_{43}Tc^{99}$			0.140		
Iodine	$_{53}I^{123}$	13 H	$_{52}Te^{123}$			0.159		
	$_{53}I^{125}$	60 D	$_{52}Te^{125}$			0.035	0.6	
	$_{53}I^{131}$	8.05 D	$_{54}Xe^{131}$	0.608		0.364	2.3	0.31
	$_{53}I^{132}$	2.3 H	$_{54}Xe^{132}$	1.5		0.673	12.3	
				2.12		0.777		
	$_{53}I^{133}$	20.8 H	$_{54}Xe^{133}$	1.4		0.53		
			$_{55}Cs^{133}$	0.345		0.081		
Cesium	$_{55}Cs^{137}$	29.6 Y	$_{56}Ba^{137}$	0.523		0.661	3.3	0.57
Iridium	$_{77}Ir^{192}$	74.5 D	$_{76}Os^{192}$			many	5.5	0.26
			$_{78}Pt^{192}$					
Gold	$_{79}Au^{198}$	2.7 D	$_{80}Hg^{198}$	0.959		0.411	2.5	0.30
Mercury	$_{80}Hg^{197}$	2.7 D	$_{79}Au^{197}$			0.077		
	$_{80}Hg^{203}$	46.9 D	$_{81}Tl^{203}$	0.210		0.279		
Radium	$_{88}Ra^{226}$	1622 Y	$_{82}Pb^{206}$			many	8.25	1.2
in equilibrium								
Radon	$_{86}Em^{222}$	3.83 D	$_{82}Pb^{206}$			many	8.25	1.2
in equilibrium								

RADIOACTIVE DECAY

$N = N_0 e^{-\mu t}$

N = amount present at time t   t = time

N_0 = amount present at onset $T\frac{1}{2}$ = half life

μ = decay coefficient

$\mu = \frac{0.693}{T\frac{1}{2}}$

$N = N_0\ e^{-0.693\,t/T\frac{1}{2}}$

Average life of isotope $= T\frac{1}{2} \times 1.44$

Millicuries equivalent to 1 mgm radium $= \frac{8.25\ r/hr}{K\gamma \text{ of isotope}}$

Effective life $= \frac{1}{T\frac{1}{2}\text{ eff (effective life)}} = \frac{1}{T\frac{1}{2}\text{ biol (biological life)}} + \frac{1}{T\frac{1}{2}\text{ physical}}$

Radioactive decay equilibrium of daughter isotopes

$\frac{N_1}{T\frac{1}{2}\,(1)} = \frac{N_2}{T\frac{1}{2}\,(2)}$

$\frac{\text{Number of atoms of isotope 1}}{\text{Half life isotope 1}} = \frac{\text{Number of atoms of isotope 2}}{\text{Half life isotope 2}}$

RADIOACTIVITY

1 hr = 3600 sec   1 day = 86400 sec

1 yr = 3.156×10^7 sec

Avogadro's number = 6.025×10^{23} atoms/gm atomic wt

= 6.025×10^{23} molecules/gm molecular wt

Curie (c) = 3.7×10^{10} disintegration/sec

Millicuries (mc) = 3.7×10^7 dis/sec

Microcurie (μc) = 3.7×10^4 dis/sec

Micromicrocurie ($\mu\mu$c) = 3.7×10^{-2} dis/sec

Γ = specific gamma ray constant = r/hr 1 meter from a point source of 1 curie

$K\gamma$ = r/hr 1 cm from a point source of 1 mc

Atomic# = number of protons in a nucleus (Z)

Mass# = number of mass particles in a nucleus (A)

Isotope = atoms having same atomic# (Z) but different mass# (A)

$_{53(Z)}I^{131(A)}$ Iodine 131 has an atomic #53 and mass #131

CONSTANTS AND FORMULAS

1 micron (μ) $= 10^{-3}$ mm $= 10^{-4}$ cm
1 Angstrom (Å) $= 10^{-8}$ cm
e = 2.7183
$1/e = 0.368$
$\log_e 2 = 0.693$
$\log_{10} 2 = 0.301$
$\log_{10} e = 0.434$
$\log_e 10 = 2.303$
$\log_e x = 2.303 \log_{10} x$
$\pi = 3.1416$
Circle · area $= \pi r^2$; circumference $= 2\pi r$, πd
Sphere · area $= 4\pi r^2$, πd^2; volume $= \frac{4}{3}\pi r^3$, $\frac{\pi}{6} d^3$
1 erg = 1 dyne cm
1 erg $= 6.24 \times 10^5$ MeV
1 calorie $= 4.18 \times 10^7$ ergs/gm
1 electron volt (eV) $= 1.602 \times 10^{-12}$ ergs
1 million electron volts (MeV) $= 1.602 \times 10^{-6}$ ergs
1 electrostatic unit of charge (esu) $= 2.083 \times 10^9$ electrons

Electron charge $= 4.803 \times 10^{-10}$ esu of charge
Density of air (STP) $= 0.001293$ gm/cm³
W = energy to produce ion pair = ~34 eV (in air)
Speed of light (c) $= 2.99 \times 10^{10}$ cm/sec
Speed of light (c) = n (frequency) $\times \lambda$ (wavelength)
Planck's constant (h) $= 6.625 \times 10^{-27}$ erg sec
E (ergs) = h (Planck's constant) $\times$ n (frequency)

$$E\,eV = \frac{12{,}400}{(\text{Å})} \qquad \text{minimum}^\lambda\ (\text{Å}) = \frac{12.4}{V\ (\text{keV})}$$

1 roentgen (R) produces ionization
= 1 esu of charge/0.001293 gm of dry air
= 1 esu of charge/cm³ air (STP)
$= 1.61 \times 10^{12}$ ion pairs/gm dry air
$= 2.08 \times 10^9$ ion pairs/cm³ air (STP)
$= 5.47 \times 10^7$ MeV/gm dry air
$= 7.08 \times 10^4$ MeV/cm³ air (STP)
= 93—98 ergs/gm water (or soft tissue) for photon energies from 200 kvp to 1 Mvp
1 rad = 100 ergs absorbed/gm of any absorber
$= 6.24 \times 10^7$ MeV absorbed/gm of any absorber

RADIATION ATTENUATION

$$I = I_0 e^{-\lambda t}$$

I_0 = intensity of incident beam
I = intensity of beam after traversing thickness of absorber (t)
λ = attenuation coefficient
t = thickness of absorber
$T\frac{1}{2}$ = thickness of absorber required to reduce intensity of beam by a factor of two

$$I = I_0 e^{-0.693\, t/T\frac{1}{2}}$$

INVERSE SQUARE

The dosage of radiation from a point decreases inversely as the square of the distance from the source

$$\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2}$$

I = intensity
d = distance

LENGTH

from \ to	cm	in.	ft
cm	1	0.3937	0.03281
in.	2.540	1	0.08333
ft	30.48	12	1

AREA

from \ to	cm²	in.²	ft²
cm²	1	0.1550	0.00108
in.²	6.452	1	0.00694
ft²	929.0	144	1

VOLUME

from \ to	cm³	in.³	ft³
cm³	1	0.06102	3.53×10^{-5}
in.³	16.39	1	5.79×10^{-4}
ft³	2.83×10^4	1728	1

WEIGHT

from \ to	gm	oz	lb
gm	1	0.03527	0.00220
oz	28.35	1	0.06250
lb	453.6	16	1

HYL (APPROX.) IN Pb AND TISSUE FOR COMMON BRACHY THERAPY SOURCES

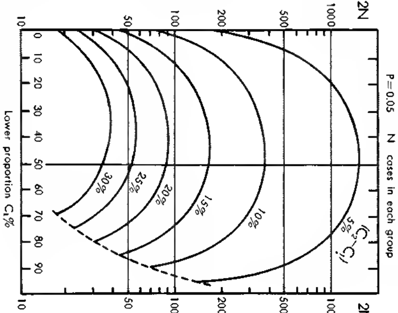
HVL (mm) \ Source	Radium	Co_{60}	Cs_{137}	Ir_{192}	Au_{198}
Pb	12.0	12.0	5.7	2.6	3.0
Tissue	110	108	81	65	65

CHARACTERISTICS FOR COMMONLY USED TELETHERAPY UNITS

~Depth (mm) Electron Equilibrium \ Unit	250 KeV	Cs_{137}	Co_{60}	6 MeV	24 MeV
	0	1.5	5	15	40
Depth – 50% dose (approx.) mm 100 cm FSD					
Pb	0.34	5.7	12	14	14
Tissue	85	100	120	160	220

MINIMUM NUMBER OF CASES REQUIRED TO REACH A SIGNIFICANT RESULT

P = 0.05 N cases in each group



N = number of cases in each treatment group
C_1, C_2 = assumed proportion cured in 1st and 2nd groups respectively
$C_2 - C_1$ = treatment difference achieved